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logging test of a single-hull BALLOON

By HILTON H. LYSONS
VIRGIL W. BINKLEY
CHARLES N. MANN

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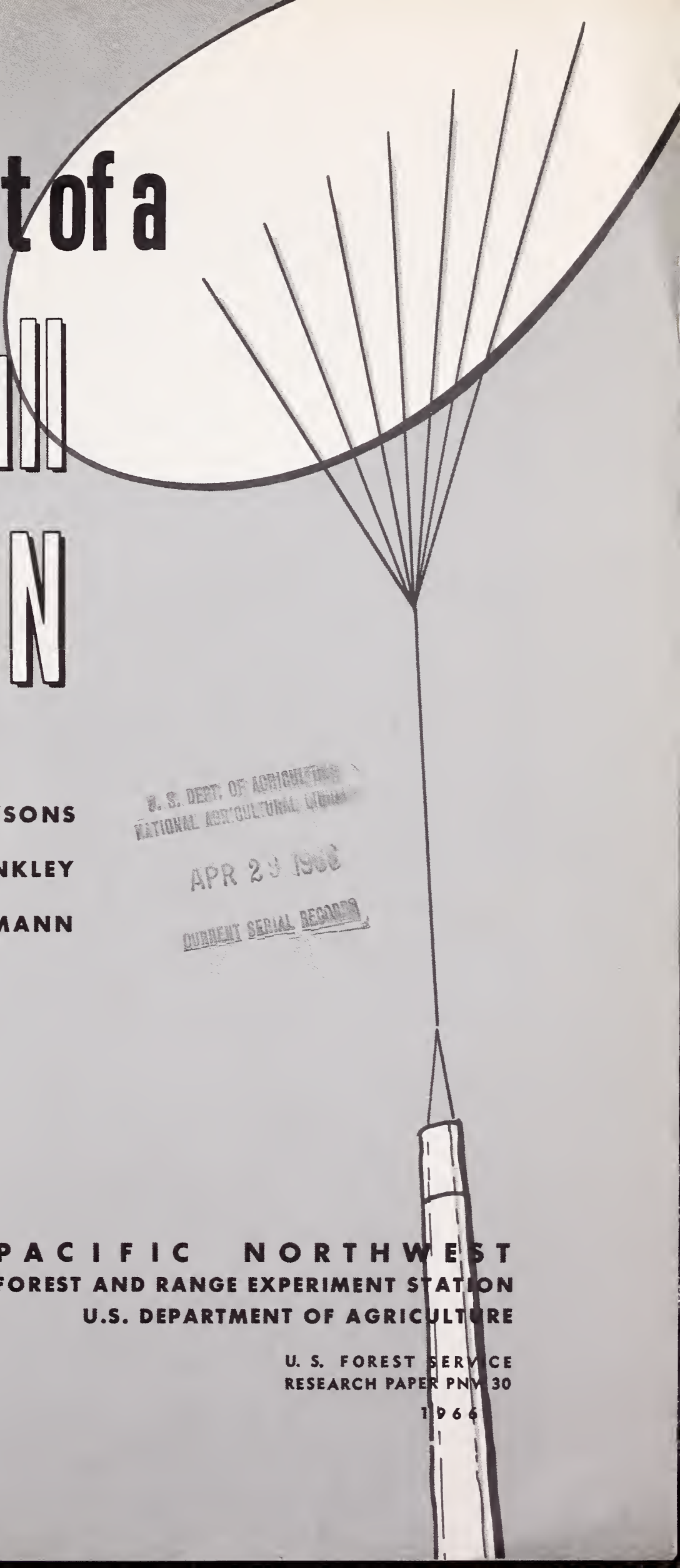
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INTRODUCTION

This test of a single-hull balloon for logging was performed early in 1965 in connection with the forest engineering research study of harvesting heavy timber from difficult access areas. Prior to this test, the only balloon logging experience in the United States was that acquired by Bohemia Lumber Co., using a twin-hull Vee-Balloon designed and built by Goodyear Aerospace Corp. Single-hull balloons had been tested in British Columbia in 1963 and 1964, but specific performance information was unavailable. The test reported here was conducted by the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, in cooperation with the Bohemia Lumber Co., Inc., of Culp Creek, Oreg. Site of the test was at Dean Creek on the Elliott State Forest near Reedsport, Oreg.

Primary test objectives were:

1. To obtain information for a dynamic analysis from which parameters for logging balloon design could be established. (Attempts to analyze the lift-off phase had previously required assumptions too numerous for a valid analysis.)
2. To determine limiting windspeeds when the balloon was yarding, tethered, and bedded down.
3. To determine structural and aerodynamic characteristics of this hull type.
4. To determine payload capability under various operating conditions.
5. To obtain logistics and reliability information.

This test was not intended to prove or disprove the suitability of this particular balloon for logging, but was intended to evaluate the characteristics of the single-hull design. The experiment was prompted by a report^{1/} which indicated that a single-hull balloon of proper design merits careful consideration for logging operations.

Logging costs were not obtained because such information would be premature at this stage of balloon system development.

^{1/} Ganzer, Victor M. Preliminary survey of single-hull vs. Vee-Balloons for logging applications. 1965. (Unpublished report on file at Pacific Northwest Forest & Range Exp. Sta., U.S. Forest Serv., Portland, Oreg.)

APPARATUS USED IN TEST

The apparatus used in this test will be described as: (1) operational equipment, (2) balloon support equipment, and (3) test support equipment. Operational equipment is defined as that necessary to perform yarding with a balloon. Balloon support equipment is that peculiar to balloon logging, not necessary to the yarding operation but required at other times. Test support equipment includes all of the apparatus used to gather data.

Operational Equipment

Figure 1 shows the arrangement of operational equipment used in this test. The various components are described in detail below.

Balloon. -- The single-hull balloon was purchased from MacMillan, Bloedel & Powell River, Ltd., of Canada, upon completion of their 1964 logging tests. This balloon was designed and manufactured in England in 1958 for use of the British Atomic Energy Authority at the Christmas Islands Test Area. MacMillan, Bloedel & Powell River purchased the balloon through Air Reel Transport, Ltd., in October 1964, and used it for logging during November and December until heavy snow halted operations. Testing with this balloon at the Dean Creek site began in February 1965.

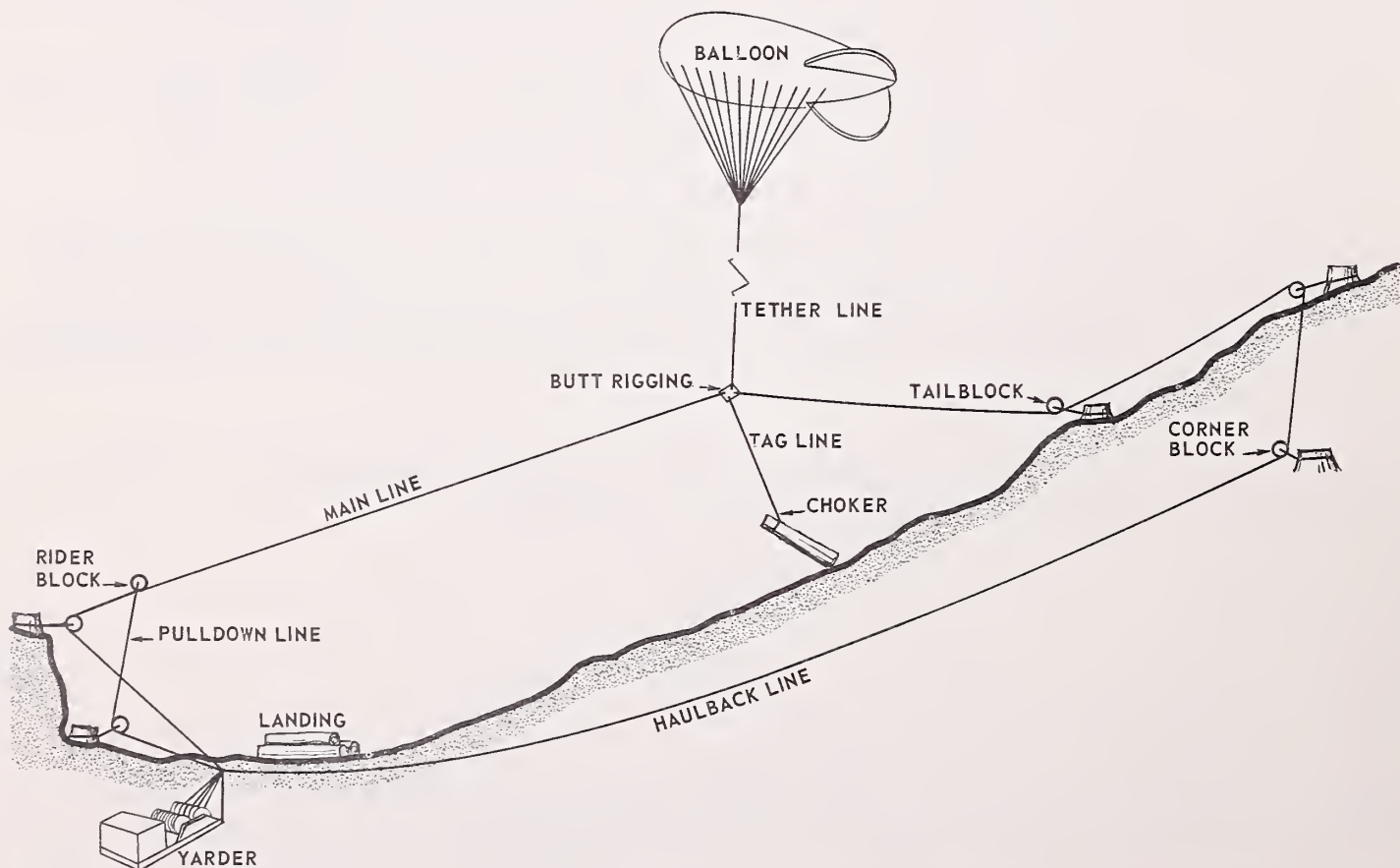


Figure 1.--Arrangement of operational equipment for single-hull balloon test.

Configuration of this British balloon is typical of the majority of tethered balloons. The balloon consisted of a streamlined hull with three inflatable tailfins. A ballonnet, or air-filled compartment, was incorporated in the lower portion of the hull and was separated from the gas section by a diaphragm. Ram-air, which entered through an airscoop, pressurized the ballonnet to maintain the hull shape in wind. The ballonnet also provided a variable hull volume for expansion and contraction of the gas. The tailfins were also inflated by ram-air and could be collapsed for bedding down. The balloon fabric was coated, two-ply, Egyptian cotton. Figure 2 shows the balloon just after release from the bedding ground with the tailfins deflated. In figure 3, the balloon is shown just before bedding down with the tailfins inflated.

Figure 2.-- Single-hull balloon just after release from bedding ground with tailfins deflated.



Figure 3.--Single-hull balloon just before bedding down with tailfins inflated.

A suspension system, consisting of twenty-four 1/8-inch-diameter steel cables, was used between the tether line and the balloon. At the balloon, the suspension cables were fastened to load patches which spread the load over an area of the balloon fabric. Two sets of ground handling lines were provided on the balloon and also attached to load patches. One set pulled the balloon to the ground at the bedding area, and the other set secured the balloon to anchors after it was lowered. The various lines can be seen in figures 4 and 5. The suspension lines attach to the lower patches seen in these figures, and the handling lines attach to the middle and upper patches.

No maintenance other than routine inspection was performed on the balloon before initial inflation. It soon became apparent, by the large volume of gas lost, that painting of the balloon was required. Hypolon paint was applied to the balloon after about 4 weeks of testing.



Figure 4.--Front view of single-hull balloon tied down at bedding ground.

Figure 5.--Side view of balloon secured at bedding ground. Cylinders contain helium for replenishment.



Yarders.-- Two yarders, manufactured by Washington Iron Works of Seattle, were used during the test period. Initially, a modified skyline yarder with a maximum main-line speed of 1,800 feet per minute was used; this was later replaced by a yarder, designed specifically for balloon logging, which had a maximum line speed of 2,500 feet per minute. The skyline yarder is shown in figure 6.



Figure 6.--Tank-mounted balloon yarder, designed and built by Washington Iron Works of Seattle, Washington.

Rigging.--As shown in figure 1, the rigging was similar to that used in high-lead yarding, except that the balloon tether line was attached to the butt rigging and provided lift at this point. A 1/2-inch-diameter main line and a 9/16-inch-diameter haulback line were used with both yarders. Two 1/2-inch tether lines were incorporated between the butt rigging and the balloon suspension (one as a load line, and the second as a safety line to prevent loss of the balloon in the event of failure of the load line). Tag lines varied from 50 to 150 feet, depending on the terrain and landing areas.

Communications.--A radio link provided voice signals between the yarder operator and the choker setters.

Balloon Support Equipment

The balloon support equipment consisted of equipment required at the bedding area and that required to transfer the balloon between the bedding ground and the logging site.

Bedding area equipment. -- The bedding area was covered by a ground cloth to protect the hull fabric from possible chafing and puncture. Logs anchored the tiedown lines and also secured blocks through which the pulldown lines passed. A crawler tractor, to which the pulldown lines were attached, was used for the actual pulldown operation and remained in position while the balloon was bedded down. Sandbags secured the deflated tailfins and stabilized the balloon in high winds. Figures 4 and 5 show the balloon bedded down.

Transfer equipment. -- A truck with a two-drum winch transported the balloon between the bedding ground and the logging site. A 3,000-pound counterweight was placed at the rear of this truck to counteract the balloon lift and sidepull in a wind.

Test Support Equipment

Test support equipment consisted of a 16-mm. movie camera, a dynamometer, a staff compass, two recording anemometers, and forms for recording test data. One anemometer was located at the bedding area and recorded the average windspeed at 15-minute intervals. The other anemometer, capable of providing continuous velocity readings, was located at the logging site on a ridge approximately 1,000 feet above the landing.

TESTS

All the various tests performed in this study were part of an actual logging operation. This is not always the most favorable way to conduct engineering research, but available funds did not allow for performing any portion of the test in a more completely controlled environment.

Logging tests were conducted on two units of the Bohemia Lumber Co.'s timber sale in the Elliott State Forest. The first unit was located at the head of a small stream drainage with steep, broken slopes. The position of the landing and presence of small side ridges in this unit required that some turns be started from the far side of the ridges, and nearly all turns had to pass over side ridges on the way to the landing. The maximum yarding distance in the first unit was approximately 2,000 feet. In the second unit, yarding was done from a facing hillside with a landing at the bottom of the slope. The maximum distance yarded in this unit was approximately 1,200 feet. In both units, the direction of yarding was basically east, and prevailing winds were either from east or west. The bedding area was located approximately 1 mile from the logging units.

Operating and supervisory personnel of the Bohemia Lumber Co. performed the logging and balloon handling, and Forest Service personnel observed the tests and collected data. Testing was also witnessed by representatives of several balloon manufacturers.

Duration of the testing was to have been not more than 3 months, beginning on or about February 8, 1965. The balloon arrived on this date and was in operation until March 3, 1965, when operations were suspended to paint the balloon and to await arrival of the new balloon yarder. Operations resumed on April 21, 1965, and continued until May 4, 1965, when a total balloon failure ended the tests.

Survival Test

This test was conducted to establish the safe wind limits while the balloon was yarding, while it was tethered in the unit, and while it was bedded down and, also, to point out potential stability and structural problems inherent in this hull design. The operation was observed and events indicating survival problems were recorded. In this report, the term "survivability" is used as a measure of the ability of the balloon to withstand the effects of wind.

Operational Test

The operational test was performed to obtain a cycle time and maximum payload comparison between turns which were yarded with one end in contact with the ground and those which were yarded free of the ground. Selected logs were weighed and a record kept of the manner in which they were yarded.

Lift-Off and Flying Test

The purpose of this test was to determine the relationships of the various forces acting during the initial phases of log motion and to determine the approximate magnitude of the drag resistance encountered in flying logs on downhill slopes. Attempts were made to carry out this test by photographically recording the relative angles of the lines and by weighing selected logs.

Logistics Test

The logistics test was performed to indicate the support and maintenance requirements of the single-hull balloon. The test was conducted by observing and recording setup, scheduled maintenance, initial gas inflation and replenishment, and transfer operations between bedding ground and logging unit.

Reliability Test

This test was performed to indicate the reliability of the single-hull design. A record was kept of each balloon failure, its cause, and the yarding time lost due to the failure.

RESULTS AND DISCUSSIONS

During the first phase of testing, the only serious problem was the excessively high rate of gas leakage. At the start of the second phase, the Forest Service requested the operator to see if the balloon's structural capability could be reached by inducing the heaviest possible loads. When this procedure was followed, a series of small balloon failures resulted, which, together with the intentionally severe loading, resulted in a complete failure.

Table 1 presents a general time study of the single-hull balloon test. The table was compiled from daily log sheets kept during the test. Times were divided into the following categories:

Setup. -- Time required for inspection, initial inflation, and arrangement of bedding ground after which the balloon was available for yarding.

Balloon scheduled maintenance. -- Time required for preventive maintenance, including gas replenishment and inspection.

Balloon handling. -- Time required to make the transition between a secured, tied-down status at the bedding ground and an operational status in the unit.

Balloon unscheduled maintenance. -- Time required for corrective maintenance following repairable balloon failures.

Wind delays. -- Periods when winds prevented yarding or moving the balloon from the bedding ground.

Road changes and equipment maintenance. -- Time required to correct malfunctions of the rigging and yarder as well as time for block and road changes and yarder moves. Also included in this item are all miscellaneous delays not caused by the balloon, such as radio malfunctions.

Actual yarding. -- Time during which yarding took place.

Survival Test

The survival test did not furnish data as complete as desired due to failure of the wind-recording instruments and, in some cases, lack of sufficient winds to cause survival problems. The anemometer at the logging unit was to record both speed and direction. However, the direction recorder failed to function entirely, and the speed readings appeared to be in error. A post-test repair and calibration of this anemometer verified its poor condition at the time of the test and pointed out the need to adequately check out instrumentation before testing begins. Due to the instrumentation problems, windspeeds for the survival tests were estimated.

Table 1.--General time study of single-hull balloon test on

Elliott State Forest, Oregon, 1965

(Hours)

Date	Setup	Balloon scheduled maintenance	Balloon handling	Balloon unscheduled maintenance	Wind delays	Road changes and equipment maintenance	Actual yarding
First phase:							
Feb. 8	4.0	0	0	0	0	0	0
9	8.0	0	0	0	0	0	0
10	9.0	0	0	0	0	0	0
11	4.0	0	0	0	0	4.0	0
12	0	1.3	1.3	0	0	2.8	2.6
13	0	0	1.0	0	0.8	1.4	4.3
15	0	1.5	1.3	0	0	1.6	4.1
16	0	1.0	1.2	0	0	1.0	5.3
17	0	.5	1.0	0	0	3.7	3.3
18	0	1.2	.3	0	0	2.1	4.9
19	0	0	.5	0	0	1.3	6.2
20	0	0	0	0	0	8.0	0
22	0	.5	0	0	0	7.5	0
23	0	1.0	1.2	0	0	4.9	.9
24	0	0	0	0	0	8.0	0
25	0	0	1.3	0	0	6.2	1.5
26	0	.5	1.5	0	2.0	3.4	1.1
Mar. 1	0	.5	1.0	0	5.2	0	1.8
2	0	.5	.5	0	3.0	.8	3.7
3	0	0	1.0	0	0	4.5	2.5
Second phase:							
Apr. 21	0	0	1.0	0	0	0	3.0
22	0	0	1.0	0	0	1.0	6.0
23	0	.5	1.0	0	0	1.0	6.0
26	0	.5	.5	0	0	4.0	3.0
27	0	0	0	0	0	2.5	5.5
28	0	0	0	5.5	0	1.5	1.0
29	0	.5	1.5	0	0	1.5	4.5
30	0	0	0	0	0	8.0	0
May 3	0	.5	.5	3.0	0	.5	4.0
4	0	.5	.5	.7	.3	0	.5
Total	25.0	11.0	19.1	9.2	11.3	81.2	75.7

When winds reached a velocity estimated at 15 miles per hour, the flight path of the balloon became erratic. Yarding was stopped to prevent injury to personnel due to unpredictable line movements and, also, to prevent fouling the tether line in trees near the landing. During these periods, the balloon was allowed to rise to approximately 1,500 feet above the landing by letting out the main and haulback lines. When this height was reached, the balloon became stable. This behavior indicated that a longer tether line would enable logging to continue in winds higher than the 15 miles per hour which, in this test where a 500-foot tether line was used, caused a stoppage in logging operations.

The anemometer at the bedding ground worked intermittently, and readings obtained were judged to be low; therefore, estimates of wind velocity at the bedding ground had to be substituted for actual data. The maximum windspeed encountered during periods when the balloon was bedded down was estimated to be a steady 15 miles per hour with gusts up to 30 miles per hour. The problems encountered in this wind were: movement of anchor logs not secured to the ground, movement of the balloon over the inboard anchor logs, and violent flapping of the deflated tailfins which had pulled loose from the anchoring sandbags. Later, sandbags were hung from the pulldown-line attachment points on the balloon, as shown in figure 5. It is believed that this would have prevented some of the balloon motions. However, high winds did not occur again before the end of the test. Problems caused by wind at the bedding ground point out the need to study use of natural or constructed wind barriers and deflectors. A better system is required for securing the deflated tailfins.

While the balloon was being moved between the logging site and the bedding ground, any crosswind, coupled with the forward motion of the truck, resulted in a circular oscillation of the balloon. On several occasions, the truck had to be stopped to prevent fouling of the tether line in the trees. Side motions of the balloon caused by wind had a tendency to lift one side of the truck. Transfer operations between the truck and the butt rigging in a wind were complicated by swinging of the tether lines.

These experiences indicated that, if the balloon was to be bedded down for a severe wind, it would have to be moved and secured when conditions were still reasonably calm. Best survival in wind was obtained when the balloon was tethered about 1,500 feet above ground.

Operational Test

In the operational test, yarding logs completely free of the ground (flying) was compared with yarding with one end in contact with the ground (dragging). Payload capability and cycle times were compared by weighing selected logs and performing a limited time study of the operation.

This procedure indicated a payload limit of approximately 4,500 pounds for flying and approximately 6,100 pounds for dragging. Static lift of the balloon was approximately 2,400 pounds at the time these logs were yarded. This is

only an indication of the payload capability of the balloon, since capability depends on the slope, inhaul speed, and wind velocity. Both of the payloads mentioned above were yarded with an average slope of 30 percent, a yarding distance of approximately 1,200 feet, and calm wind conditions. Flying induced almost no dynamic loads into the balloon after the log was free of the ground, but dragging produced loading which became severe when hangups occurred.

Inhaul speeds for dragging logs were lower than for flying logs to avoid log breakage. However, since inhaul was a relatively small portion of the total yarding cycle time, the difference between dragging and flying cycle times was not appreciable. The average cycle time was 6 minutes with an average yarding distance of about 1,200 feet. Loads averaged 1.48 logs per cycle during the test.

A few logs were carried back up the hill, after being yarded down to the landing, to obtain a comparison between uphill and downhill yarding. Analysis before the test had shown that, in downhill logging, components of the balloon dynamic lift, drag, and inertia all combine with the static lift to provide an upward force on the log. However, uphill logging produces drag and inertia components which act opposite to the static lift. This analysis was verified by the comparison. It was observed that logs easily flown downhill had to be dragged slowly back up the hill. The reduction in speed was necessary to keep the downward drag force component from exceeding the lift forces. Therefore, uphill yarding resulted in an increase in yarding time and a decrease in payload capability. These field observations and analysis indicate that only downhill yarding should be considered when a balloon yarding system similar to that used in this test is to be employed.

Lift-Off and Flying Test

The lift-off and flying test failed to determine, through photographic records of line angles, the relationship of forces which occur while yarding. Factors contributing to the failure of this test include: inaccessibility of the proper position for taking photographs, due to terrain features and safety considerations; inclement weather; insufficient contrast between lines and background; and poor resolution of the equipment used. The failure of this test resulted in a study to determine better methods and equipment for obtaining load data. This study indicated that load cells in conjunction with a telemetric data link would best furnish the desired information, and equipment of this type is presently being acquired for use on future balloon tests.

Logistics Test

The logistics test, to determine the maintenance and support required by this type balloon, was conducted by observing and recording: (1) steps performed to first make the balloon available for yarding; (2) requirements for scheduled maintenance; (3) the quantity of gas for initial inflation and replenishment; and (4) the time required to transfer the balloon between the logging unit and the bedding ground.

Twenty-five hours were required to provide initial balloon availability. The following tasks were performed during this period:

1. Spread ground cloth and uncrated balloon
2. Inflated balloon with air, inspected for leaks, and deflated balloon
3. Inflated with helium
4. Arranged holddown logs and turned balloon and bedding area to face predominant wind
5. Replaced one handling line
6. Attached tether lines to suspension system

"Scheduled maintenance" refers to preventive maintenance which is normally scheduled so that it will not interfere with logging. In this test, a maintenance schedule was not established before the test, but routine preventive maintenance, such as replenishment of helium, periodic inspection, and minor repairs, was recorded as scheduled maintenance. This term is used to distinguish preventive maintenance from unscheduled or corrective maintenance which generally causes a stoppage in logging. During the operation, 11 hours of scheduled maintenance were required, primarily for helium replenishment.

Initial inflation was performed by filling the balloon until it appeared to have the proper shape and tightness. No metering device was used during the filling operation, and the amount of gas used for initial inflation was not known until several weeks later when the billing was received. The amount of gas used and the high initial static lift indicated that the balloon was overfilled during initial inflation. A total of 83,944 cubic feet was used for initial inflation, which resulted in a static lift of 3,300 pounds on the day following inflation. It was found during the test that the balloon was properly inflated when it had a static lift of approximately 2,500 pounds. With this static lift, the balloon was quite soft when bedded down but would attain the proper shape and firmness when the ballonet became pressurized by ram-air during operation. Use of a gas as expensive as helium requires development of better procedures to avoid overfilling a ballonet-type balloon. The time to inflate the balloon was less than 1 hour.

During the first phase of testing, an excessive amount of helium was required for replenishment. Painting the balloon significantly reduced gas leakage. During the test, 110 cylinders of helium, each containing 285 cubic feet of gas at standard atmospheric temperature and pressure, were used for replenishment.

Moving and bedding the balloon required 19.1 hours. This represents about 8 percent of the total test time. If the balloon had been allowed to remain in the logging unit overnight and brought down only for weekends, this time would have been reduced to about 2 percent. In this test, almost daily bedding was required for gas replenishment. This points out the requirement for low-permeability materials in logging balloons as well as development of a reliable balloon which will not have to be bedded frequently for inspection and repair.

Reliability Test

The reliability test was undertaken to obtain an indication of the reliability inherent in the single-hull design. High reliability and survivability are essential qualities which must be developed and designed into a logging balloon if this type of logging is to be economically successful. Other desirable characteristics will mean little to an operator if logging is continually interrupted by balloon downtime to make repairs or by instability in relatively calm winds.

The term "indicated reliability" is used in this report because, in an engineering sense, "reliability" means the probability of a system functioning in a prescribed manner for a specified period of time. Probability numbers cannot be obtained from a single test of a piece of equipment. However, reliability can be indicated by the amount of time required to perform unscheduled maintenance and by noting failure types and occurrence patterns.

Table 1 shows that 9.2 hours were required to perform unscheduled maintenance on the balloon, which was 4 percent of the total test time. No unscheduled maintenance was required during the first-phase testing, and it was only after severe balloon loading was induced in the second phase that unscheduled maintenance was required. The low requirement for unscheduled maintenance was attributed to the overall design simplicity of the balloon.

A modified skyline yarder was used during the first phase of testing, and a yarder designed and built specifically for balloon logging by Washington Iron Works of Seattle was employed during the second phase. With the modified skyline yarder, a series of delays occurred due to lines being fouled, stranded, and kinked. When this yarder was replaced by the balloon yarder, time lost for line maintenance was greatly reduced. The 8-hour delay, shown in table 1, on April 30 was required to move the yarder to a new unit.

Balloon failures near the end of the test were attributed primarily to the age of the balloon and the apparent lack of preventive maintenance during its life. It is believed that if this had been a new balloon or if the test budget had allowed a complete refurbishment prior to testing, the balloon would not have been destroyed.

During the early part of testing, previous lack of maintenance was evident. Inspection of the bag prior to initial inflation showed numerous pinholes in the fabric. Lines to hold the tailfin airscoop were missing. A seam in the side of the hull was partially delaminated. The suspension cables attach to the patches by means of a short length of fiber rope, and one fiber rope was found to be nearly severed by the cable.

On April 24, one of a series of pressure-limiting valves in the hull below the ballonnet fell out during yarding. This created a loss in the ballonnet pressure, causing the balloon to become too limp for yarding. The balloon was moved to the bedding ground where the necessary repairs were made.

On May 3, the left forward suspension cable broke during yarding. Inspection showed the cable to be badly corroded. The balloon was moved to the bedding ground where the cable was replaced.

On May 4, the tail section was torn completely off during yarding. A log, which was being dragged at the time, hung up on a stump. In working the log free with the main and haulback lines, slack was pulled in the tether line. This allowed the balloon to rise freely in a noseup attitude. At the instant that slack was removed from the tether line by the free rise of the balloon, the main line was accelerated by the yarder. A severe impact load resulted; and since the balloon was in a noseup attitude, only the front suspension lines received this load, resulting in a failure of the front suspension lines as well as violent pitching and rolling of the balloon. This motion and the tension in the tether line caused failure of most of the remaining lines as well as one of the suspension line attachment patches. Finally, a patch near the tail of the balloon was torn out, initiating a tear which continued around the entire hull. Figure 7 shows the balloon after the failure. Repair was considered impractical due to the age and condition of the balloon.



Figure 7.--Single-hull balloon after failure which ended testing.

The failure, which resulted from an impact load when the balloon was in a noseup attitude, might have been avoided if the suspension cables had not been in a weakened condition due to age and corrosion. Since a noseup attitude will always result when the balloon is allowed to rise freely, and since a suspension system designed for loading in a near horizontal attitude cannot distribute loads evenly when the balloon is in a noseup attitude, loading of this type should be avoided.

This failure occurred during planned severe loading tests and in no way reflects on Bohemia Lumber Co.'s fine performance. The failure proved valuable in that it resulted in the development of a new concept of loading and log lift-off which should prevent such failures and still safely permit the handling of heavier log loads.

It was suspected that the cotton balloon material was structurally weak due to its age, but laboratory tests after the failure showed that the fabric was surprisingly strong. The following is an excerpt from a report of a strength test performed by the Applied Science Division of Litton Industries:

Tensile strength tests were made using a 1"x6" piece of material and jaw travel of 0.02 inches per minute. Tear tests were run using a 2"x3" piece of material with a 2" slit parallel to the 3" dimension with jaw travel of 10 inches per minute.

Our conclusion from these tests is that the cotton material was not rotten. Its strength shows up favorably although the cotton is appreciably heavier than the modern fabrics. We cannot estimate the weight of the cotton because of the buildup of paint on the surface. These tests do not indicate how the materials would compare under dynamic loading or what their permeability to gas might be.

The test data were obtained on an Instron tensile testing machine used routinely by us for materials testing. However, the test methods used were one of a number of different test methods used by different companies and testing laboratories in testing these type materials. Further, we could not be certain of the detailed construction and orientation of the two-ply coated fabric in cutting our samples for test. The net result is that we believe the test results should be considered on a qualitative and not on a quantitative basis.

The test results obtained are as follows:

	<u>Wt/sq yd</u>	Tensile Strength lb/inch		Tear Strength lbs	
		<u>Warp</u>	<u>Fill</u>	<u>Warp</u>	<u>Fill</u>
Barrage Balloon (Egyptian Cotton)	13.9 oz	84	100	5.6	5.9
Neoprene Coated Dacron (Bias ply with Hypalon paint)	8.4	52	53	4.2	1.7
Neoprene Coated Nylon (Bias ply with aluminum pigmented neoprene paint)	8.3	136	103	18.5	11.6

It would seem that the old British balloon stood up very well with time and that failure was due to either dynamic loads or to progressive failure of the load lines.

TEST OBSERVATIONS AND CONCLUSIONS

1. Survivability. -- Movement of the balloon between logging site and bedding ground in relatively low-velocity winds presented handling problems. Instability, which stopped logging in winds exceeding an estimated 15 miles per hour, was attributed to the short (500 feet) tether line.

2. Payload capability and cycle time. -- Turns weighing up to 4,500 pounds were yarded with logs free of the ground, and turns weighing up to 6,100 pounds were yarded with one end of the logs in contact with the ground. Average cycle time was 6 minutes, and average turn consisted of 1.48 logs.

3. Dynamic force data. -- Photographic methods to aid in determining balloon yarding forces failed to provide the desired information. Future tests should be instrumented to obtain this information.

4. Reliability. -- Although balloon failure ended testing of the single-hull design, high reliability was indicated by the low requirement for unscheduled maintenance during the test.

5. Logistics. -- Better procedures are necessary to avoid overfilling a ballonnet-type balloon. Gas leakage, which was a problem during the first phase of testing, was corrected by painting the balloon. Scheduled maintenance of the single balloon, other than gas replenishment, was negligible.

6. Application. -- Primary application of balloon logging systems will be yarding downhill, where the logs can be pulled away from facing slopes and where the long yarding distance available with these systems can substantially reduce roadbuilding cost.

RECOMMENDED RESEARCH

The experience gained in this test and observations made of other balloon logging operations, as well as discussions with representatives of balloon manufacturers, have indicated several areas requiring engineering research to produce an optimum balloon logging system. The following are primary research areas:

1. Ammonia as inflation gas. -- One of the most serious problems observed in balloon logging trials has been the cost of helium. The price of helium varies, depending on the location. In the Washington-Oregon coast area, the initial inflation gas, delivered by tank truck, costs approximately 6 cents per cubic foot, and the replenishment gas, contained in standard helium cylinders, costs approximately 10 cents per cubic foot. In less accessible areas, the price will be considerably higher. With a 100,000-cubic-foot balloon and an assumed annual leakage of 100,000 cubic feet, this represents \$6,000 for initial inflation and \$10,000 a year for replacement.

Another problem related to the cost of helium is the reluctance of an operator to deflate a balloon when high winds are expected. Equipment is commercially available for recompressing helium but the present expense of such equipment is prohibitive, so deflation means loss of the valuable gas. Reluctance to dump the gas can result in loss of a balloon as well as the gas.

This problem becomes minor by the use of ammonia gas to provide lift, and a thorough investigation of the feasibility of using this gas is recommended. Ammonia will provide approximately half of the buoyant force of helium, but the cost of ammonia is relatively insignificant. About \$150 worth of ammonia will fill a 100,000-cubic-foot balloon. The investigation to determine the feasibility of using ammonia should include the following:

- (a) Study the hazards involved in using ammonia
- (b) Determine requirements for compatible materials in balloons and inflation systems used with ammonia
- (c) Design a gas generation system to provide the heat necessary for quick vaporization of the ammonia
- (d) Design a balloon system to provide the desired performance characteristics with ammonia as an inflation gas
- (e) Test an ammonia-filled balloon yarding system

2. Dynamic analysis.--Payloads have been yarded considerably in excess of the static lift of the balloons being used. The additional lifting force is obtained from a combination of balloon inertia, aerodynamic lift, aerodynamic drag, and, in some cases, from main and haulback line tensions.^{2/}

The exact relationship of these various forces during log pickup, skidding, and yarding is unknown and cannot be determined without data from some fully instrumented tests. This information is necessary to perform a dynamic analysis of balloon yarding which will provide design parameters for an optimum balloon system. It is recommended that instrumented tests be performed to provide data on line tensions and balloon velocity and acceleration for an analysis.

3. Configuration studies.--Up to this test, balloons have not been designed for logging. The basic shape of a balloon will influence the performance, reliability, and survivability and may also influence the initial cost, stability, and gas consumption. It is recommended that a study of various balloon shapes be performed. Results of the dynamic analysis are necessary to perform this study.

^{2/} Mann, Charles N. Forces in balloon logging. Pacific Northwest Forest & Range Exp. Sta. U.S. Forest Serv. Res. Note PNW-28, 5 pp., illus. 1965.

Basically, a balloon consists of an envelope which contains the lifting gas. On some balloons, airfoils are provided for lift and stability. These airfoils are usually pressurized by gas, ram-air, or an airblower system. Research is necessary to determine the requirements for airfoil surfaces and to determine the best pressurization system. Consideration should also be given to the use of noninflatable high-lift and drag devices.

A dilation system is used for gas expansion and contraction, due to changes in altitude and temperature, and also to maintain an internal pressure to resist wind pressure on the hull. Three systems are in current use today, namely:

- (a) Expandable tension sections
- (b) Ram-air pressurized ballonnet
- (c) Electric-blower pressurized ballonnet

Studies are needed to determine the most reliable and efficient dilation system.

4. Balloon logging carriage. --In downhill balloon logging, any load that can be lifted off the ground can be yarded into the landing. When a load is moving toward the landing, relative wind produced by the balloon motion provides dynamic lift, which, together with the static lift, supports the load. During log pickup in still air, loads in excess of the balloon static lift require an additional upward force. In this test, the additional force was produced by pulling slack in the tag line. This allowed the balloon to rise freely until the slack was removed, at which time deceleration of the balloon produced an impact load on the logs. At the same instant, the main line was accelerated to keep the logs in the air and start them into the landing.

Several problems were encountered with this type of loading. The short duration of the impact load and slack in the main line required precise timing to keep the logs in the air. Drag force limited the free rise velocity of the balloon. The noseup attitude of the balloon, which resulted from the free rise, caused unbalanced loading of the balloon suspension cables. This unbalanced loading destroyed the test balloon.

The experience gained in this test pointed out the requirement for a different method of lift-off loading, which led to a new balloon-logging-carriage concept shown in figure 8. Operation is shown in figure 9. After chokers are secured to the logs, the main line is let out, allowing the balloon to rise. When the balloon has reached the desired height, the main line is rapidly pulled in, which induces an upward pull on the logs and a downward pull on the balloon. Motion of the balloon is opposed by static lift, inertia, and drag; and these forces combine to lift the logs. A bumper fitting on the line above the tag line fixes the length of the tag line to facilitate choker setting and log landing. Design and testing is required to develop this concept.

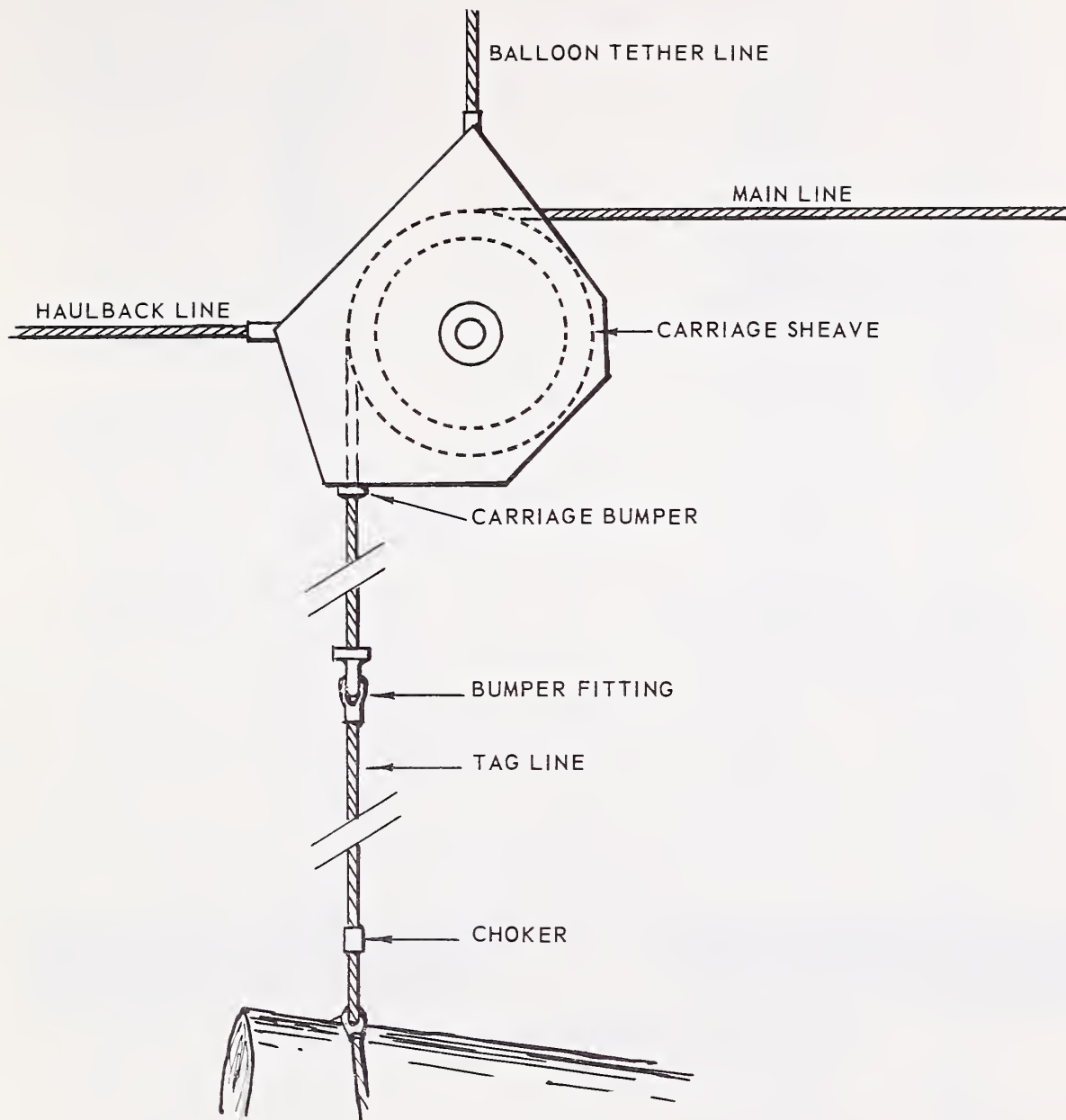


Figure 8.--Balloon logging carriage.

Secondary balloon logging research should be performed in the following areas:

1. Deicing. -- Balloon logging has great potential in areas where wet snow is prevalent. However, a small amount of wet snow will overcome the static lift of the balloon. Deicing chemicals, coatings, and hull shapes should be investigated as possible solutions to this problem.

2. Personnel transportation. -- Extended downhill yarding carries with it the costly problem of crew transportation. A suitable carriage or gondola should be designed for transportation of personnel. Indications are that this can be safely accomplished with the balloon.

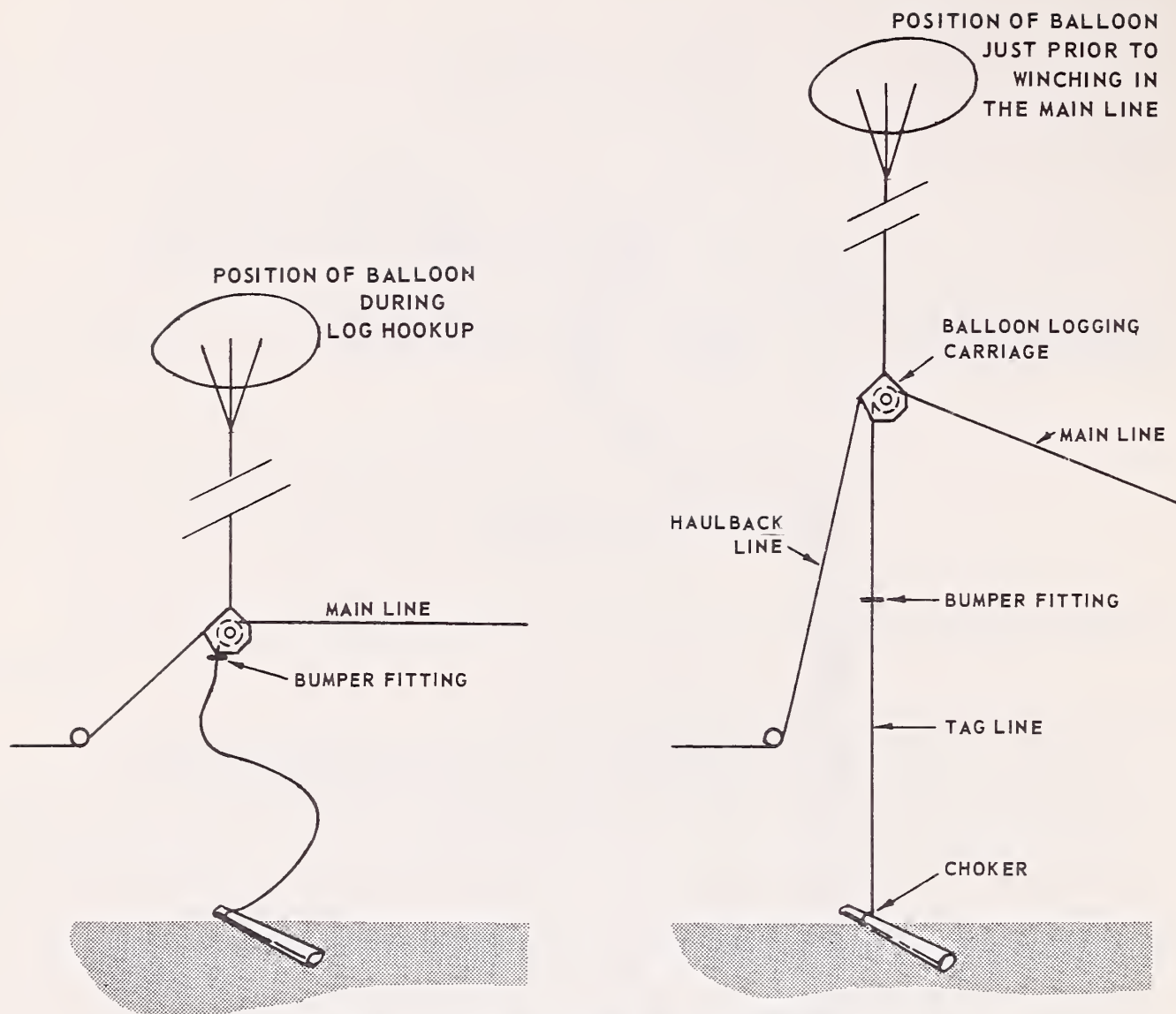


Figure 9.--Balloon logging carriage operation.

3. Ground handling and tiedown. -- Previous tests have shown that balloon survivability is greatly dependent on proper ground handling and tiedown. Further studies are needed to develop suitable procedures for handling and tiedown under logging conditions.

Lysons, Hilton H., Binkley, Virgil W., and Mann, Charles N.
1966. Logging Test of a Single-Hull Balloon. U.S.
Forest Serv. Res. Paper PNW-30, 20 pp., illus.
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Station, Portland, Oregon.

A single-hull balloon was tested under actual logging conditions to reveal necessary design requirements and problem areas as a basis for further development of balloon logging.

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